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Original Article

# Do changes in middle-distance running kinematics contribute to the age-related decline in performance?

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**Abstract**

**Objectives**: The aim of this study was to assess ageing-related changes in middle-distance running kinematics and performance in master athletes. **Methods**: Male athletes (n=157; 57±13.3 years) competing in the 800- and 1500-m runs at the German Master Athletics Outdoor Championships 2018 were filmed and the bending-over angle, brake angle, leg-stiffness angle, propulsion angle and hip-flexion angle measured. **Results**: Leg-stiffness and propulsion angle decreased with age (all p<.001), while bending-over, brake and hip-flexion angle increased (all p<.001). Bending-over, propulsion and hip-flexion angles were smaller in 800- than 1500-m races, while the brake angle was larger in 800- than 1500-m races (all p<.001), with no significant difference in leg-stiffness angle between disciplines. In the last round, hip flexion was lower compared to earlier rounds in both distances (p<.001). Age was the major predictor for performance in both races (800-m $R_{adj}^2$=0.74; p<.001, 1500-m $R_{adj}^2$=0.80; p<.001), with a minor impact of technique (improved $R_{adj}^2$ to 0.84 and 0.86, respectively). **Conclusions**: The study revealed that the ageing-related decline in running performance of master athletes was primarily explicable by age with only a small contribution of changes in sprint kinematics.

**Keywords:** Aging, Endurance, Performance, Track and Field, Video Analysis

## Introduction

Most elderly people do not reach the minimum physical activity levels needed to prevent disease and frailty and maintain independence[1]. Reduced physical activity is associated with declines in stroke volume, muscle aerobic capacity and muscle mass that contribute to a reduced $VO_{2max}$ and exercise tolerance[2]. The importance of reduced physical activity is further reflected by an almost twice as high $VO_{2max}$ in lifelong endurance-trained master athletes than age-matched sedentary adults[3]. Master athletes maintain high levels of physical activity in old age and thus offer scientists a unique possibility to disentangle the effects of reduced physical activity from ageing *per se*[4-8].

The number of master athletes participating in endurance-based events has increased steadily over the last decades[2]. While short distance sprints require mainly speed, middle-distance running relies on a combination of speed and endurance[9]. The physiological profile, including aerobic capacity and anaerobic ability, is essential for success, and distinguishes middle-distance runners from long-distance runners and sprinters[10]. Performance, however, is not only determined by metabolism, but also by running economy, measured as the oxygen cost of running at a given velocity, that may be influenced by kinematics[11]. The higher energy cost of running in master athletes compared to young athletes may be the consequence of ageing-related changes in running technique[12]. To our knowledge, ageing-related changes in kinematics in endurance-based disciplines such as 800- and 1500-m runs, have not been previously studied. If characteristic ageing-related and performance-relevant changes in kinematics could be identified, one of the targets of training programs for elderly athletes could be to normalize these

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changes in running kinematics to compensate the ageing-effect as much as possible.

In a previous study, we revealed specific age-related changes in kinematics in short sprints[13]. The objective of this study was to assess age-related changes in the kinematics of middle-distance running (800- and 1500-m runs) in master athletes, and the contribution of these changes to the ageing-related decline in running performance to identify deficits that can be particularly addressed by exercise regimes. We hypothesized that at least part of the ageing-related decline in running performance of master athletes are related to altered kinematics.

## Materials and methods

RWTH Aachen University Hospital IRB approved the study (reference number EK 300/17, date of approval: October 11, 2017). Videos were recorded at the German master track and field championships in Mönchengladbach, Germany on June 29th and 30th, 2018. Data were anonymised according to the declaration of Helsinki.

### *Subject selection*

All male participants who successfully completed an 800-m and/or 1500-m race were included in the study. Athletes between the age of 35 and 94 who reached the minimum performance criteria[A] in seasons 2017 or 2018 and had an official start license could register for the event. The athletes were allocated to 5-year category groups, beginning at the age of 35 (35-39, 40-44, 45-49 etc.).

### *Materials*

A Nikon D3300 camera (Nikon, Düsseldorf, Germany) with a 35-mm focal length Nikon DX VR lens was used for video recording at 60 frames per second and a 1080-pixel resolution. The position of the camera, mounted on a tripod, was identical for the 800-m and 1500-m races (Figure 1). All angles were computed orthogonally.

### *Software and video analysis*

The method applied was previously published[13]. The software Kinovea version 0.8.15 (Joan Charmant & Contrib., Bordeaux, France) was used to measure the angles. The same person measured all angles by hand and the frame selection was based on visual inspection to reduce the risk of measurement errors. Five angles (Figure 2) were measured: bending-over angle, brake angle, leg-stiffness angle, propulsion angle (during ground contact) and hip-flexion angle (in the flight phase). Bending-over angle, the angle between a vertical line through the hip and the upper body, and brake angle, the angle between a line from the hip to the

[A] https://www.dlv-xml.de/Storage/EventFiles/18L0000000100 5102/482965.pdf

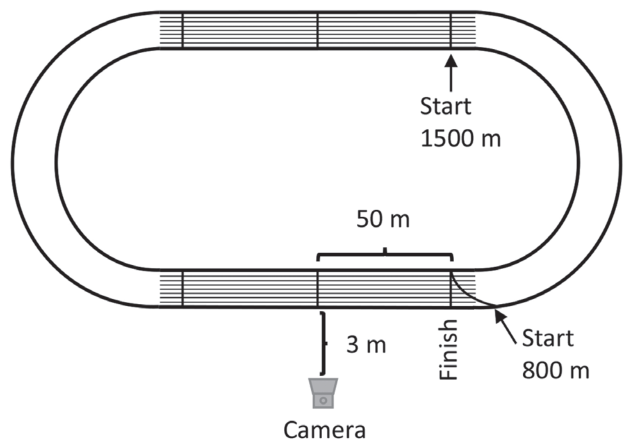


**Figure 1.** Camera location, start and finish lines.

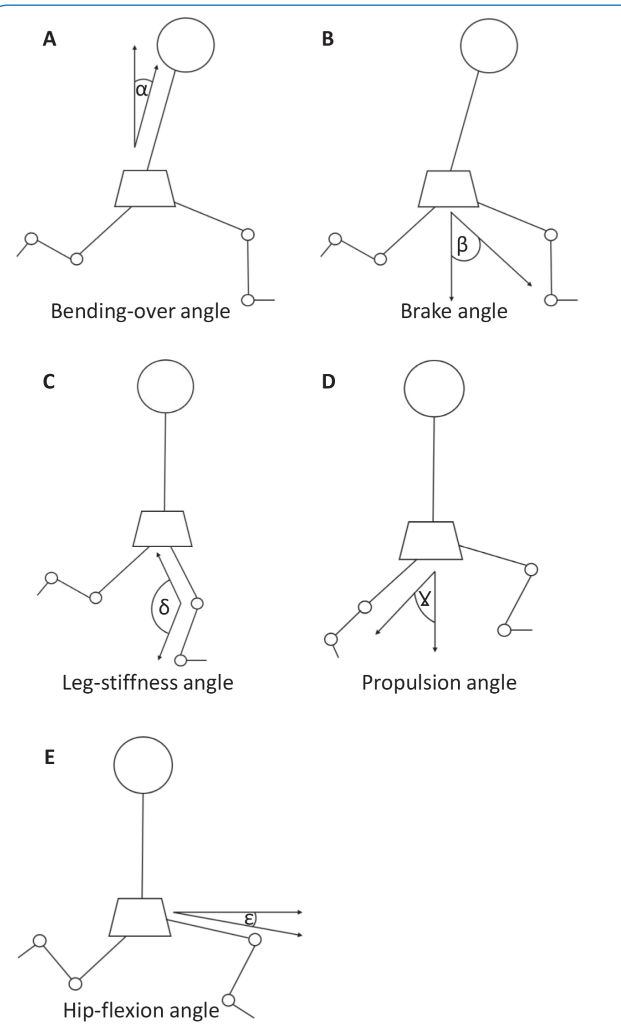


**Figure 2.** **A**: bending-over angle (α), **B**: brake angle (β), **C**: leg-stiffness angle (δ), **D**: propulsion angle (γ), **E**: hip-flexion angle (ε). Angles modified and in the style of Dahl et al. 2019[13].

heel and a perpendicular line through the hip, were measured at first contact of the foot on the ground. Leg-stiffness angle (knee angle) was measured when the hip was straight above the foot. Propulsion angle, the angle of a vertical line through the hip and a line from the hip to the foot, was measured at the end of the ground contact phase, at the last contact of the foot tip on the ground. Hip-flexion angle was measured in the flight phase, when the angle between a horizontal line through the hip and a line through the knee was minimal. In 800-m races, each athlete was recorded twice (at 350 and 750 m into the race) as the camera was passed twice during the race. In 1500-m races, each athlete was recorded four times (at 250, 650, 1050 and 1450 m into the race). Race results and age were taken from the website of Nordrhein track and field association[B].

*Statistical analysis*

Statistical tests were conducted with IBM® SPSS® Statistics version 25. Age effects on performance were investigated using one-way analysis of variance. Two-way analyses of variance were conducted to get information about the effects of age and discipline on the measured angles. If a significant age*discipline effect was revealed, we performed one-way analyses of variance for 800-m and 1500-m races separately. The individual changes of the angles throughout the race were examined using repeated-measures analyses of variance with two levels for 800-m and four levels for 1500-m races. A pairwise comparison between each round of the analysis was included. Stepwise regression analyses were executed to assess the contribution of age and the different kinematic angles to performance. The model excluded factors that did not correlate significantly with performance. Significance was assumed at $p<0.05$. Data was uploaded to the figshare online database.

## Results

Overall, 157 individual races were recorded (Table 1): 83 master athletes were analyzed in 800-m and 74 in 1500-m races. Data from six participants were excluded from the study (3 in 800-m and 3 in 1500-m races) due to masking. The oldest athlete in the study was 86 years old and the average age was 57±13.3 years.

*Age and discipline impacts on technique*

Performance in both the 800- and 1500-m races declined with age ($p<.001$; Figure 3A). The bending-over angle was smaller in the 800-m compared to the 1500-m competition ($p<.001$) and increased with age ($p<.001$) in both disciplines (Figure 3B). Brake angle was larger in 800- than in 1500-m races ($p<.001$) and increased with age ($p<.001$) in both disciplines (Figure 3C). For the leg-stiffness angle, no significant difference was found between the two disciplines, but the angle decreased with age ($p<.001$), irrespective of discipline (Figure 3D). The propulsion angle was smaller in 800- than in 1500-m races ($p<.001$) and decreased with age ($p<.001$), independent of discipline (Figure 3E). The hip-flexion angle was smaller in 800- compared to 1500-m races ($p<.001$) and increased with age ($p<.001$), irrespective of discipline (Figure 3F).

**Table 1.** Numbers of participants.

| Age Group | 800-m | 1500-m |
|---|---|---|
| 35-39 | 13 | 11 |
| 40-44 | 6 | 4 |
| 45-49 | 4 | 6 |
| 50-54 | 11 | 11 |
| 55-59 | 10 | 9 |
| 60-64 | 11 | 11 |
| 65-69 | 9 | 9 |
| 70-74 | 7 | 6 |
| 75-79 | 7 | 4 |
| 80-84 | 5 | 2 |
| 85-89 | 0 | 1 |
| Total | 83 | 74 |

*Impact of technique on sprint performance*

Age was the major predictor of performance ($p<.001$, $R^2=.737$) in 800-m runs with some small contributions of hip-flexion ($p<.001$, adjusted $R^2=.835$) and brake angle ($p<.032$, adjusted $R^2=.844$). In 1500-m runs, age ($p<.001$, $R^2=.800$) was also the main predictor of performance, followed by hip-flexion angle ($p<.001$, $R^2=.855$).

*Changes in technique throughout the race*

Bending-over angle (Figure 4A) did not differ significantly between the two rounds in the 800-m competition. However, in the 1500-m races, the angle was smaller in round 4 compared to round 2 ($p=.003$) and round 3 ($p=.005$). The brake angle (Figure 4B) and leg-stiffness angle (Figure 4C) did not change significantly throughout the races, irrespective of discipline. The propulsion angle (Figure 4D) was increased in the second lap of 800-m ($p=.049$; round 1:23.3° vs. round 2:24.1°) and the fourth lap of 1500-m ($p<.001$) races, which is the final sprint phase in the last round of each discipline. No significant differences were detected between rounds 1-3 in 1500-m runs. The hip-flexion angle (Figure 4E) was decreased in the final laps of each discipline, compared to the other laps. In the 1500-m race, we saw a transient elevation in the second lap ($p=.017$).

[B] https://lvnordrhein.de/content/3-wettkaempfe/2-wettkampf kalender/ 1-2018/20180629-dm-senioren/dm-senioren-ergebnisse-neu.pdf

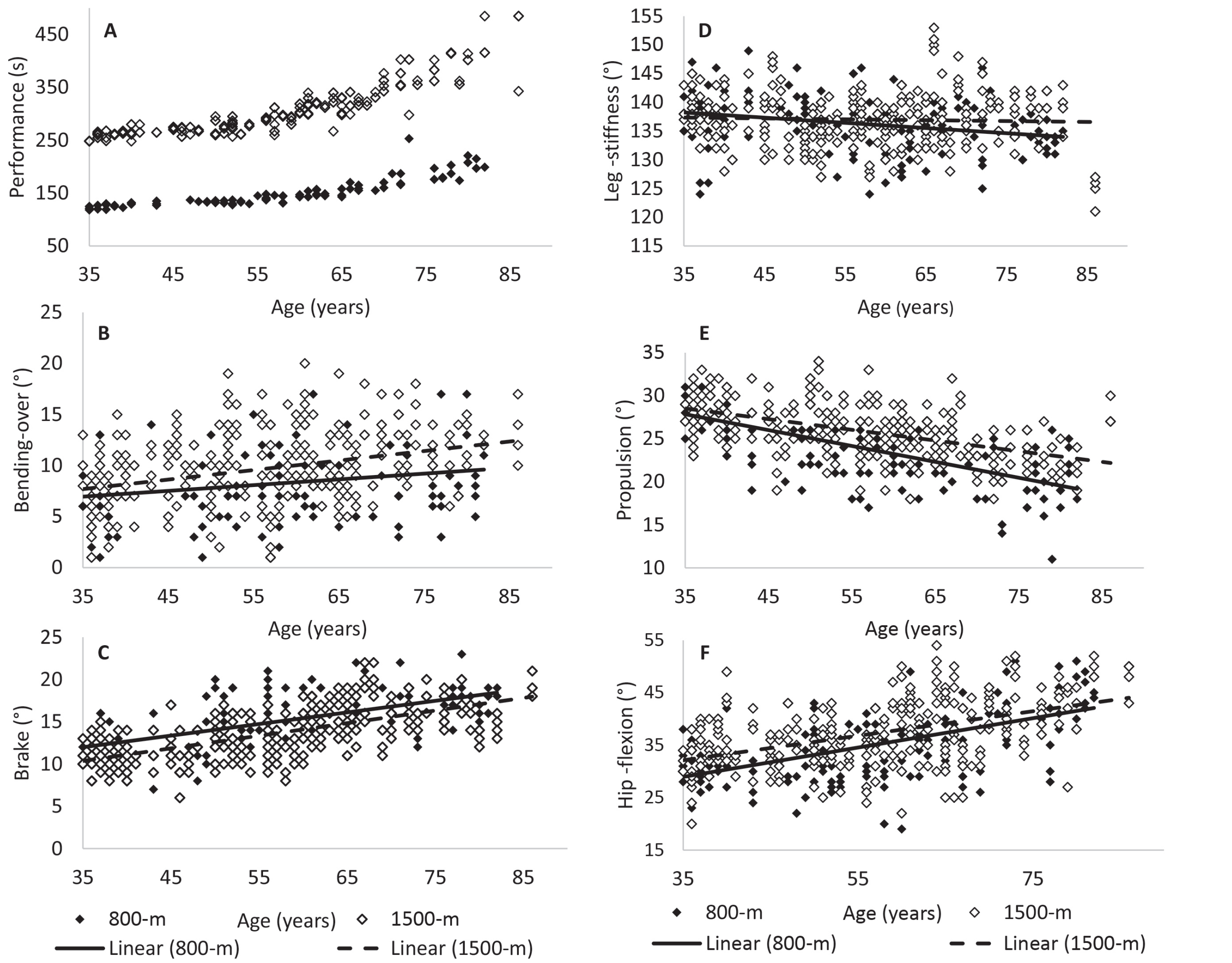


**Figure 3.** Performance and angles in the 800-m and 1500-m races vs. age. **A**: performance (800-m: p<.001, $R^2$=.74; 1500-m: p<.001, $R^2$=.78), **B**: bending-over angle (800-m: p<.001, $R^2$=.06; 1500-m: p<.001, $R^2$=.11), **C**: brake angle (800-m: p<.001, $R^2$=.35; 1500-m: p<.001, $R^2$=.42). **D**: leg-stiffness angle (800-m: p<.001, $R^2$=.06; 1500-m: p<.001, $R^2$=.002), **E**: propulsion angle (800-m: p<.001, $R^2$=.43; 1500-m: p<.001, $R^2$=.26), **F**: hip-flexion angle (800-m: p<.001, $R^2$=.29; 1500-m: p<.001, $R^2$=.24).

## Discussion

The main finding of this study was that age was the major predictor for performance in middle-distance running. While running patterns changed with age, there was only a minor impact of technique on middle-distance running performance. In addition, we found that at the end of both race types, the hip-flexion angle was decreased and in the 1500-m races, the propulsion angle was increased too, probably due to the final sprint.

The present study showed that old athletes running 800- or 1500-m races maintain roughly constant running kinematics. While many persons at age 80 and older are immobile and weak, the oldest participants in our study demonstrated a high level of endurance and fitness even at the age of 86, being far away from frailty or dependence on others.

### *Age and discipline effects on technique*

Here we confirmed that middle-distance running performance declined with age. We did not find studies on kinematics of master athletes in middle-distance races and believe our study is the first to explore this. Ageing was associated with changes in running technique in middle-distance runs. Decreases in muscle function[7] and loss of range of motion in joints due to joint degeneration and tissue stiffness[14] may play a crucial role in the ageing-related change in running technique.

The ageing-related increase of bending-over angle with

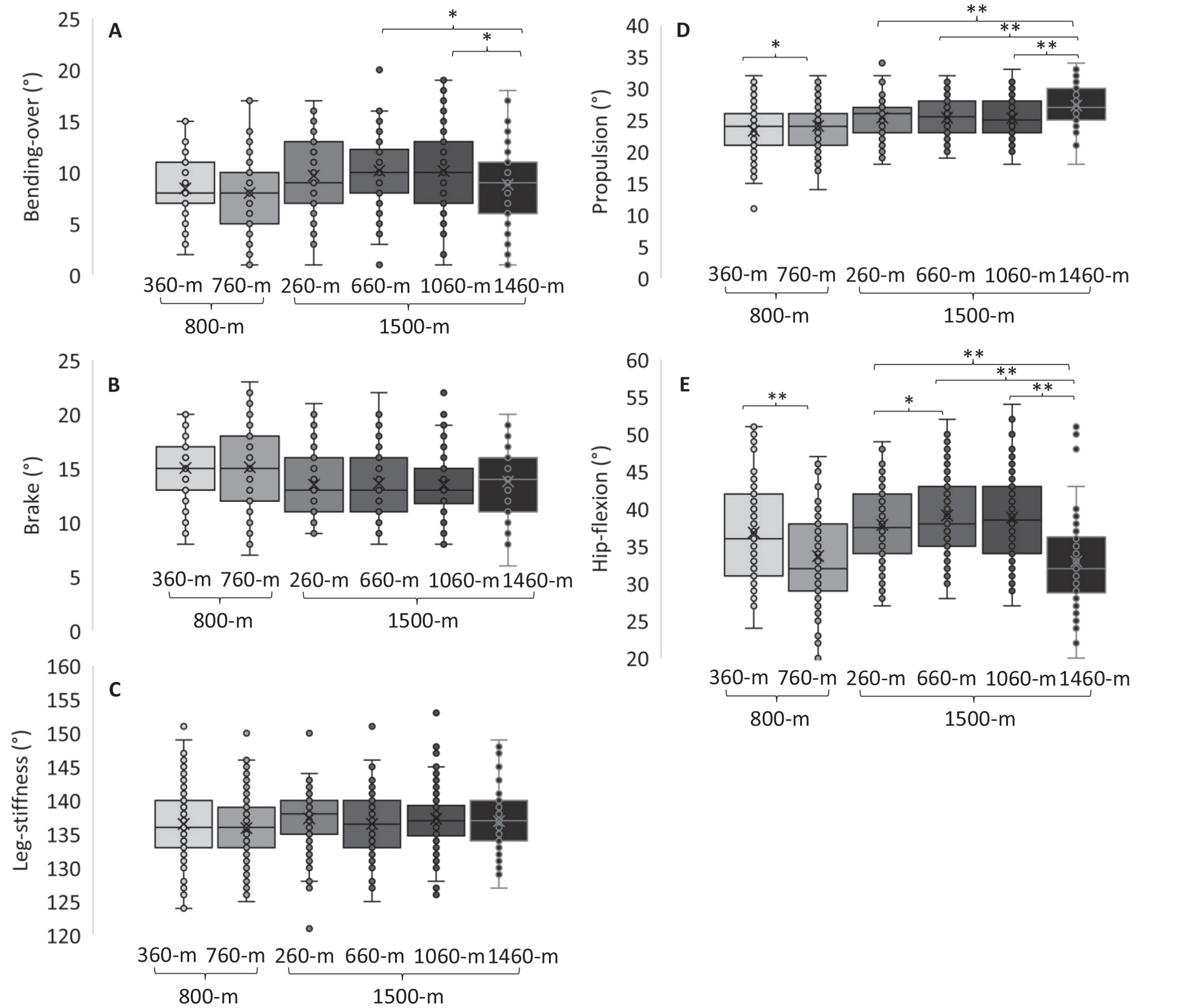


**Figure 4.** Boxplots of the angles at different moments during the 800- and 1500-m races. **A**: bending-over angle, **B**: brake angle, **C**: leg-stiffness angle. **D**: propulsion angle, **E**: hip-flexion angle (*p<.05, **p<.001).

age may be caused by a loss of flexibility in the spine[15] and loss of muscle force in the paraspinal muscles[16], but the impact of a low flexibility of the spine and low paraspinal muscle force on bending-over angle during a run has hitherto not been investigated.

Running economy has been reported to be negatively related to horizontal braking forces[17] that were represented by brake angle in our study. Hence, the larger brake angle in 800- than in 1500-m races may indicate that running economy is optimized with increasing race distance, while the ageing-related increase in brake angle may contribute to the reduced running economy[12] and thereby contribute to the reduced performance in old age.

The ageing-related increase in hip-flexion angle indicates a decreased hip flexion, which could be attributable to a lower strength of the hip flexors. The smaller propulsion angle may result in a decreased push off duration and hence acceleration duration during push off that in turn may result in a shorter flight phase and lower running velocity.

In a previous study, maximal oxygen uptake, stride length, power and aerobic capacity limited the performance in 1500-m, while peak velocity, $VO_{2max}$ and thigh length were significant predictors of performance in 800-m runs[18]. This indicated that 800-m runners had a different physiological profile from 1500-m runners[18] and/or that the strategies for best performance in each race differ. In fact, the latter is suggested by our observation that the propulsion and hip-flexion angles were lower in the 800- than the 1500-m races. Furthermore, the bending-over angle was smaller and brake angle larger in 800- compared to 1500-m runners, suggesting a different running technique between disciplines throughout the run.

*Performance*

The main predictor for performance in our current work was age, which explained almost 74% of the variation in performance. The hip-flexion angle correlated negatively with performance, in line with previous studies[19-21] and explained an additional 10%, while brake angle contributed an additional 1% of the variation in the 800-m performance. These small contributions of technique to performance led to the assumption that running performance rather declines through the loss of muscle strength and power, reduced oxygen uptake and other physiological changes during ageing than changes in kinematics[22-24], even in master athletes[25]. This also suggests that the ageing-related changes in running kinematics are caused by, rather than the cause of, these other ageing-related changes.

*Changes in running kinematics during a run*

Elliot and Roberts found that fatigue in middle-distance running led to a decreased stride length, increased step frequency, decreased hip extension (propulsion angle in our study) at the end of the support phase and a more forward leaning trunk (larger bending-over angle in our study) in college level runners[26]. This is opposite to our observation where the propulsion angle increased, and hip-flexion angle was decreased in the final lap. However, the last measurement was 50 m before the finish line, and it is likely that these changes are rather an effect of sprinting for the last 50 m to the finish, rather than an effect of fatigue, and the changes seen by Elliot and Roberts occurred only at 2900 m into a race[26]. In both 800- and 1500-m races the hip-flexion angle was reduced in the last round, and again, rather than ascribing this to fatigue, it is most likely an adaptation of kinematics related to the final sprint. Combining the data of our study with those by Elliot & Roberts[26] suggests that effects of fatigue on running kinematics have a bigger impact in longer races, and to assess this further, longer running distances should be studied in the future, such as 5,000-m or 10,000-m races.

*Limitations*

Both disciplines were filmed from the same spot with the same distance to the finish line. The angles were measured from an orthogonal perspective, so that we could only measure angles in the recorded plane, while running is performed in three-dimensional space. The low number of participants beyond the age of 80 years suggests we need to be careful with extrapolating these data to athletes older than 80 years. Another limitation is the fact that we filmed only once every 400 meters, and therefore provide relatively few data-points. However, more frequent filming is not expected to significantly alter the outcome of the study. Regarding the camera settings and resolution, data confirm sufficient quality. Moreover, the cross-sectional study design and the fact that we only measured kinematic data, without measurements of kinetic data are further limitations.

*Practical applications*

The present study revealed characteristic changes of running kinematics with age, that were most likely attributable to weak trunk muscles and a reduced range of motion in the hips. Athletes, fitness programs and geriatric physiotherapy may benefit from this information by addressing these issues with specific exercises. These should improve trunk muscle stability and hip range of motion. Further studies should investigate if this improves walking ability, quality of life and reduces risk of falls.

## Conclusion

The present study shows that the ageing-related decline in middle-distance running is primarily a function of age (800-m: 74%; 1500-m: 80%), and although ageing is accompanied by alterations in running kinematics, they have little impact (at best 11%) on the ageing-related decline in performance. This is similar to a previous observation in sprinting disciplines[13]. The changes in kinematics are most likely caused by age-related physiological parameters, such as reduced muscle mass, $VO_{2max}$ or joint movement. Decreased range of hip motion and weak trunk muscles are two parameters that may be specifically addressed by master athletes and physiotherapists to gain an extra 10% in performance.

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